MASTER OF SCIENCE
IN
OPERATIONS RESEARCH

INTERDICTING ELECTRICAL POWER GRIDS
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This thesis explores Benders decomposition for solving interdiction problems on electric power grids, with applications to analyzing the vulnerability of such grids to terrorist attacks. Some existing optimization models and algorithms are refined and extended, and the value of these techniques is demonstrated using standard reliability test networks from IEEE.

Implementation of Benders decomposition optimally solves any problem instance, in theory. However, run times increase as Benders' cuts are added to the master problem, and this has prompted additional research to increase the decomposition's efficiency. Empirical speed ups are demonstrated by dropping slack cuts, solving a relaxed master problem in some iterations, and using integer, but not necessarily optimal, master-problem solutions. These mixed strategies drastically reduce computation times. For example, in one test case, the optimality gap and the time that it takes to achieve this gap is reduced from 16% in 75 hours to 5% in 16 minutes.

KEYWORDS: Electric Power Grids, Network Interdiction, Mixed Integer Programming

TWO-PERIOD, STOCHASTIC SUPPLY-CHAIN MODELS WITH RECOURSE FOR NAVAL SURFACE WARFARE
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The minimum-cost procurement and allocation of anti-ship cruise missiles to naval combat ships is modeled as a two-period stochastic integer program. Discrete scenarios in two periods define "demands" for missiles (i.e., targets and number of missiles required to kill those targets), which must be met with sufficiently high probabilities. After the former combat period, ships may replenish their inventories from a depot if desired and if the available depot inventory suffices. A force commander optimizes ship-to-target assignments to meet demands. The basic model solves slowly, so constraints to enforce reasonable operational directives and add valid inequalities are added. These improvements reduce the solution time by 95% for the test case. Instances with up to six ships and five scenarios in each period then solve in less than one hour on a 2 GHz personal computer.

KEYWORDS: Inventory Models, Target Assignment, Integer Programming

HOW TO OPTIMIZE JOINT THEATER BALLISTIC MISSILE DEFENSE

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Many potential adversaries seek, or already have, theater ballistic missiles capable of threatening targets of interest to the United States. The U.S. Missile Defense Agency and armed forces are developing and fielding missile interceptors carried by many different platforms, including ships, aircraft, and ground units. Given some exigent threat, the U.S. must decide where to position defensive platforms and how they should engage potential belligerent missile attacks. To plan such defenses, the Navy uses its Area Air Defense Commander (AADC) system afloat and ashore, the Air Force has its Theater Battle Management Core Systems (TBMCS) used in air operations centers, and the Missile Defense Agency uses the Commander's Analysis and Planning Simulation (CAPS). AADC uses a server farm to exhaustively enumerate potential enemy launch points, missiles, threatened targets, and interceptor platform positions. TBMCS automates a heuristic cookie-cutter overlay of potential launch fans by defensive interceptor envelopes. Given a complete missile attack plan and a responding defense, CAPS assesses the engagement geometry and resulting coverage against manually prepared attack scenarios and defense designs. Enemy courses of action are expressed as a mathematical optimization to maximize expected damage. It is then shown how to optimize U.S. defensive interceptor pre-positioning to minimize the maximum achievable expected damage. Researchers can evaluate exchanges where each of the defending platform locations and interceptor commitments are hidden from or known in advance by the attacker. Use of a laptop computer can produce a provably optimal defensive plan in minutes.

KEYWORDS: Optimization, Mathematical Programming, Joint Theater Ballistic Missile Defense

ANALYSIS OF SURFACE SHIPS ENGINEERING READINESS AND TRAINING

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This thesis analyzes engineering readiness and training onboard United States Navy surface ships. On the west coast, the major contributor to training is the Afloat Training Group, Pacific (ATGPAC). The primary objective is to determine whether the readiness standards provide pertinent insight to the surface force Commander and generate alternatives that may assist in better characterization of force-wide engineering readiness.

The Type Commander has many questions that should be answered. Some of these are addressed with Poisson and binomial models. The results include: first, age of a ship has no association with performance of drills and that the number of discrepancies is associated with the performance of drills; second, drill performance decreased from the first initial assessment (IA) to the second IA; third, on average, the number of material discrepancies decreases from the IA to the underway demonstration (UD) for ships observed over two cycles; fourth, good ships do well on four programs; finally, training is effective.

A table characterizing ships as above average, average, or below average in drill effectiveness at the IA and UD is supplied.

KEYWORDS: Data Analysis, Non-parametric Statistics

USING AGENT BASED MODELING TO EXAMINE THE LOGISTICAL CHAIN OF THE SEABASE

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This thesis examines a 2015 Marine Expeditionary Brigade scheme of maneuver as the baseline scenario for a commercial logistics support software program called SEAWAY. Modifications to this scenario are conducted using a designed experiment in order to explore how the plan characteristics relate to eleven specified input factors. Multiple regression analysis is used to fit models to the resulting data for three different measures of performance: Total Aircraft Sorties, Total Aircraft Sortie Time, and Total Aircraft Tons. The results suggest the plan performance is predicted well by a small subset of the factors and their interactions.

One implication of this work is a better understanding of which factors are key determinants of the plan characteristics for variations on this specific base scenario. By using these fitted models, the number of SEAWAY runs needed to identify acceptable plans should decrease dramatically. The approach in this thesis provides a blueprint for similar analyses of other scenarios by demonstrating how information gained from models fit during an exploration phase might allow the logistician to quickly determine factor settings that yield an acceptable plan once details of an operation become available. Finally, working with the SEAWAY developers provided them with some new insights.

KEYWORDS: Agents-based Models, Seabasing, SEAWAY, Latin Hypercube Design, LHC Design, Scheme of Maneuver, SOM, Marine Expeditionary Brigade, MEB

HOW TO OPTIMALLY INTERDICT A BELLIGERENT PROJECT TO DEVELOP A NUCLEAR WEAPON

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Despite decades of energetic international control efforts, nuclear weapons technology continues to spread worldwide. To understand how these complex weapons programs can be developed, researchers assume the role of a nation seeking to build a first fission weapon, and the ability to continue to build more. A large-scale project management model that includes alternate development paths to achieve certain key technical milestones is introduced. It is shown how such a project can be optimally accelerated by expediting critical tasks. Next, a new analysis tool to detect vulnerabilities in such a development program is presented: optimal actions to impede, set back, and/or otherwise frustrate completion of a first weapon are sought, even if the proliferator knows what is being done to delay things. This two-sided project evaluation tool is implemented with a combination of commercial-off-the-shelf project management software, optimization software, and custom code. An illustrative case study of a first fission weapon program shows how this new analysis tool can be used. Methods used also apply to chemical, biological, and/or radiological dispersion weapons, as well as to more conventional strategic industrial and commercial activities.

KEYWORDS: Project Management, Network Interdiction, Nuclear Nonproliferation